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The variation of the normal air temperature over the Northern Hemisphere during the year.

by

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(METEOROLOGICAL OFFICE)

AIR MINISTRY
METEOROLOGICAL RESEARCH COMMITTEE.

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Summary

Tables are given for calculating, on alternative hypotheses, the best fitting two term harmonic representation of 12 monthly mean values of a meteorological variable. One of these tables is used to estimate the harmonic parameters for the annual temperature variation for each of 305 stations covering the Northern Hemisphere, based on the monthly mean temperatures for the period 1921-1940. Charts showing the variation of the harmonic parameters over the hemisphere are described. A table is described giving the normal temperature, derived from the two term harmonic at 5-day intervals throughout the year for 280 of the 305 stations. The stability of normal temperatures computed in this way is discussed.

1. Introduction

This work arises directly from investigations under the Meteorological Research Programme, Part 2, 5(a) and (b) into the magnitude and persistence in time and space of temperature anomalies.

Weather anomalies are departures from a more or less well-defined normal state of the atmosphere, and our study of them is beset by two difficulties, depending on the time unit over which the data we look at are averaged. If the time unit is very short, an hour or a day, for example, it proves almost impossible to assemble the relevant data, or to assimilate their meaning when assembled. If the time unit is too long, important features will be obscured by the process of averaging. The optimum time unit for any purpose is the longest which shows all the important anomalies while smoothing those of shorter duration. To do this the time interval should last for only a fraction, perhaps not more than one half or one third of the lifetime of the important anomalies. The choice of the best, or at any rate a suitable time unit for use in long range forecasting is a fundamental question which does not seem to have been investigated fully. An investigation into this question is now in progress, but in the meantime we can be sure of one thing. General synoptic experience is that many significant anomalies last for much less than a month, so the time unit used in investigating them should also be less than a month. To study anomalies averaged over periods shorter than a month, we must have normals for the same shorter periods. Hence to examine the magnitude and geographical extent of significant temperature anomalies we must know the normal temperatures for periods less than a month, over the relevant area, which certainly covers a large part of the Northern Hemisphere. We are faced with the problem of preparing temperature normals for particular days, or periods of a few days, when generally the only data we have to go on are monthly mean temperatures.

The present work seeks to solve the problem on the assumption, for which the justification lies in previous work, Craddock (1955), that the normal form of the annual temperature variation is given accurately enough by the two term harmonic form

$$T = a_0 + a_1 \cos\theta + b_1 \sin\theta + a_2 \cos 2\theta + b_2 \sin 2\theta \qquad \text{-----(1)}$$

The method is to find the values of the constants which best fit the observed monthly mean temperatures, and then find the normal for any individual day, or other period by harmonic synthesis. This may seem a roundabout way to estimate a quantity of which a crude estimate can be made by simple graphical interpolation between monthly mean values, but in fact it has a great deal to recommend it. The harmonic parameters are easy to manipulate, and to interpret, while it appears in the course of the investigation that they can be estimated very accurately. The fact that the estimation is quite objective means that it is possible and worthwhile to calculate statistics describing the anomalies of temperature in detail. Finally, now that the groundwork has been done, the whole process of calculation is efficient and reliable, and suitable for performance by either mechanical or electronic calculating machines.

2. The mathematical background

The harmonic analysis of monthly mean values has usually been carried out by treating all the months as of equal length, and the errors involved in doing this have been discussed by inter alia Forbes (1860) and Bilham (1918). The validity of this treatment may be open to argument and the present approach, which does not treat the months as of equal length, is thought to be more satisfactory theoretically, while being just as easy to use.

If it is assumed that the normal temperature variation at a station is of the two term harmonic form given by equation (1) in which θ is measured from zero at midnight on December 31st, and increases by 2π during the year then the problem is to find the parameters a_0, a_1, b_1, a_2, b_2, which give the best fit to the observed monthly mean temperatures.

When a Fourier analysis is carried out on a series of equally spaced observations covering the basic period, the successive harmonics are best fitting approximations to the observations by the criterion of least squares, and they are orthogonal in the sense that the omission of one harmonic or the inclusion of an extra one does not affect the values of the rest. If, however, the observations are at unequal intervals we must decide whether they should all be treated as of equal importance in fitting the harmonic form, and in general the harmonics will not be orthogonal. For this reason we cannot without further investigation use Weihrauch's solution (1890) quoted by Pollak (1948) which calculates six harmonics from monthly mean values (and therefore fits the data exactly) when we intend to use only two harmonics.

Assuming that the year has exactly 365 days, we can write down the value of θ corresponding to every day of the year, and by means of equation (1) express the temperature for that day as a linear function of a_0, a_1, b_1, a_2 and b_2. If this expression is written down for each day in a given calendar month, summed and divided by the number of days of the month, we obtain an estimate of the monthly mean temperature. If we denote by r_i the difference between this estimate and the observed temperature for the i^{th} month then r_1 is a linear function of the parameters a_0, a_1, b_1, a_2 and b_2. We now seek the best fitting values of these parameters by minimising

$$S = \sum_{i=1}^{12} w_i r_i^2 \qquad \text{--------(2)}$$

where w_i is a positive weighting coefficient which measures the importance we attach to a discrepancy between observed and estimated values in the i^{th} month. The solutions are

$$\frac{\partial S}{\partial a_0} = \frac{\partial S}{\partial a_1} = \frac{\partial S}{\partial b_1} = \frac{\partial S}{\partial a_2} = \frac{\partial S}{\partial b_2} = 0 \qquad \text{------(3)}$$

giving 5 simultaneous equations from which the five parameters can be obtained as linear expressions of the twelve observed monthly mean temperatures.

Before solving these equations, we must decide on the weighting coefficients w_i. If the monthly mean temperatures were derived from a two term harmonic form, so that a perfect fit was possible, then all the residuals would be zero, and the choice of weighting coefficients would be a matter of indifference. Although a perfect fit is impossible, we do from our previous investigation expect a very good fit, so that the residuals should be very small. Hence if we choose weighting factors which are not quite the best, as we are compelled to in order to bring the calculation within the bounds of possibility, we may still get a fit which is not appreciably worse than the best. There are three obvious ways of choosing the weights:-

(1) We may make them all equal. This is simple, but not logically consistent, since we are trying to allow for the months being of unequal length. Moreover, it offers no advantages in time saving compared with the next alternative. On this hypothesis, a_o will be the mean of the 12 monthly means, and not the true annual mean. This case is not considered further.

(2) We may make the weights equal to the number of days in the respective months. This is logically correct if on all calendar days the temperature is equally variable, and if the serial correlations between temperatures on consecutive days are either all zero, or at least independent of the time of the year. These conditions are not satisfied strictly by any observed series of temperatures. Nevertheless, it is hard to suggest a better hypothesis for use when we have no prior knowledge of the variability to be expected at each station, and, as mentioned above, any resulting discrepancies are likely to be small, so this hypothesis was used in the practical work which follows.

(3) We may make the weights inversely proportional to the observed variances of the monthly mean temperatures for each station. This hypothesis, which includes the preceding one as a special case, ensures that a discrepancy in a month for which the temperature is very variable should be treated as of less account than an equal discrepancy in a more uniform month, which is just as it should be. However, to apply this hypothesis strictly it would be necessary, not only to calculate the variance of monthly mean temperature for each month for each station, but also to solve the equations (3) afresh for every station. It was quite impracticable to do this, but nevertheless it seemed desirable to provide some means of judging how the best fit would be altered because the monthly mean temperatures are more variable in some months than in others. So three typical weighting patterns were chosen, in the hope that any station for which the second hypothesis was inadequate might conform closely enough to one of these. The five linear simultaneous equations (3) can be solved by algebraic methods to give a_o, a_1, b_1, a_2, b_2 as linear functions of the monthly mean temperatures T_1, T_2 - - - T_{12}. Instead, however, the equations were solved numerically for twelve special cases, namely, those in which one monthly mean temperature was equal to unity, and all the rest were zero. The solutions on the second hypothesis (weights equal to the number of days in each month) were obtained by Mr. A. Gilchrist by relaxation methods and are given in Table 1 in the form suitable for practical use.

/Table 1

Table 1

Multipliers for finding the coefficients of the two term harmonic form $a_0 + a_1 \cos\theta + b_1 \sin\theta + a_2 \cos 2\theta + b_2 \sin 2\theta$ from 12 monthly mean values of a meteorological variable

Monthly mean	Multipliers to give:-					
	a_0	a_1	b_1	a_2	b_2	Sum
T_1	.0849	.1655	.0455	.1526	.0904	.5389
T_2	.0767	.1111	.1088	.0034	.1621	.4621
T_3	.0849	.0490	.1646	-.1486	.0971	.2470
T_4	.0822	-.0389	.1616	-.1530	-.0786	-.0267
T_5	.0849	-.1185	.1242	-.0081	-.1776	-.0951
T_6	.0822	-.1598	.0467	.1453	-.0929	.0215
T_7	.0849	-.1669	-.0409	.1572	.0823	.1166
T_8	.0849	-.1227	-.1201	.0037	.1777	.0235
T_9	.0822	-.0444	-.1604	-.1476	.0891	-.1811
T_{10}	.0849	.0432	-.1664	-.1551	-.0864	-.2798
T_{11}	.0822	.1168	-.1184	-.0023	-.1726	-.0943
T_{12}	.0849	.1655	-.0455	.1526	-.0904	.2671

In use the 12 monthly mean temperatures are written in column and are multiplied in turn by the columns in Table 1 to give the respective harmonic coefficients. The final column provides a sum check (i.e. if the calculation is correct, the result of multiplication by this column will tally with the sum of the harmonic coefficients).

The solution on the other three hypotheses were obtained by electronic means under the direction of Mr. F. H. Bushby, and are given in Tables 2, 3 and 4.

Table 2

Monthly mean	Weighting coeff.	Multipliers to give:-					
		a_0	a_1	b_1	a_2	b_2	Sum
T_1	.1242	.0866	.1610	.0574	.0868	.0732	.4650
T_2	.0946	.0693	.0969	.0928	.0091	.0924	.3605
T_3	.1333	.0836	.0580	.1478	-.0700	.0953	.3147
T_4	.2188	.0932	-.0270	.1802	-.1471	.0081	.1074
T_5	.3731	.0851	-.1309	.1392	-.1012	-.1673	-.1751
T_6	.5780	.0637	-.1597	.0325	.1199	-.2107	-.1543
T_7	1.2195	.0994	-.1728	-.0631	.3291	.1017	.2943
T_8	.8772	.0913	-.1030	-.1005	-.0942	.2964	.0900
T_9	.4587	.0681	-.0544	-.1330	-.2048	.0364	-.2877
T_{10}	.3984	.0904	+.0325	-.2051	-.1186	-.1680	-.3688
T_{11}	.2227	.0810	.1239	-.1197	.0639	-.1325	.0166
T_{12}	.1621	.0882	.1756	-.0284	.1272	-.0249	.3377

/Table 3

Table 3

Monthly mean	Weighting coeff.	Multipliers to give:- a_0	a_1	b_1	a_2	b_2	Sum
T_1	.1136	.0839	.1538	.0490	.0941	.0717	.4525
T_2	.0926	.0672	.1035	.0807	.0280	.0966	.3760
T_3	.1563	.0875	.0730	.1553	-.0803	.1129	.3484
T_4	.2778	.1009	-.0379	.2067	-.1835	-.0152	.0710
T_5	.3125	.0716	-.1343	.1099	-.0562	-.1794	-.1884
T_6	.4000	.0730	-.1644	.0244	.1516	-.1662	-.0816
T_7	.5263	.0936	-.1510	-.0386	.2282	.0821	.2143
T_8	.5556	.0934	-.1212	-.1003	-.0269	.2633	.1083
T_9	.4167	.0699	-.0612	-.1522	-.2085	.0689	-.2831
T_{10}	.3571	.0844	.0409	-.1966	-.1344	-.1577	-.3634
T_{11}	.2222	.0892	.1373	-.1164	.0634	-.1497	.0238
T_{12}	.1409	.0855	.1615	-.0219	.1244	-.0274	.3221

Table 4

Monthly mean	Weighting coeff.	Multipliers to give:- a_0	a_1	b_1	a_2	b_2	Sum
T_1	.1136	.0888	.1548	.0463	.1088	.0650	.4637
T_2	.1111	.0793	.1149	.0933	.0233	.1163	.4271
T_3	.1471	.0754	.0657	.1373	-.0822	.1090	.3052
T_4	.3030	.0932	-.0337	.2111	-.2086	-.0159	.0461
T_5	.3704	.0808	-.1508	.1215	-.0366	-.2130	-.1981
T_6	.3333	.0796	-.1550	.0137	.1834	-.1230	-.0013
T_7	.3030	.0838	-.1312	-.0374	.1752	.0838	.1742
T_8	.3704	.0967	-.1416	-.1015	-.0122	.2329	.0743
T_9	.2941	.0671	-.0661	-.1405	-.1753	.0791	-.2357
T_{10}	.3333	.0916	.0550	-.2136	-.1548	-.1494	-.3712
T_{11}	.1923	.0857	.1423	-.1097	.0596	-.1486	.0293
T_{12}	.1177	.0781	.1457	-.0204	.1193	-.0362	.2865

In each case the weighting factors corresponding to the solution in question are given in the first column.

Comparison between the four solutions shows that the calculation of the first harmonic is much the same on any hypothesis, but that the evaluation of the second harmonic depends much more on the hypothesis used. The question how much difference this makes in the final results has not yet been investigated fully owing to the difficulty till recently of calculating the monthly variances and the harmonic coefficients on a scale large enough to enable a reliable comparison to be made. In what follows the second hypothesis, incorporated in Table 1, has been used throughout. The monthly mean values corresponding to any set of values of the harmonic parameters can be found by using Table 5 in a similar way.

Table 5

Multipliers for finding the monthly mean values corresponding to given values of the coefficients of the two term harmonic form $a_0 + a_1 \cos\theta + b_1 \sin\theta + a_2 \cos 2\theta + b_2 \sin 2\theta$

	J	F	M	A	M	J	J	A	S	O	N	D	Sum
A_1	.9532	.7078	.2810	-.2319	-.6820	-.9493	-.9596	-.7062	-.2649	.2482	.6948	.9532	.0443
B_1	.2605	.6927	.9474	.9614	.7151	.2771	-.2359	-.6912	-.9528	-.9565	-.7038	-.2605	.0535
A_2	.8207	.0207	-.7991	-.8510	-.0451	.8060	.8447	.0205	-.8190	-.8330	-.0123	.8207	-.0262
B_2	.4849	.9615	.5197	-.4359	-.9522	-.5144	.4419	.9530	.4935	-.4635	-.9561	-.4849	.0475

3. The basic period and data

The basic period of years from which the normals are to be calculated must be long enough to reduce errors due to the peculiarities of individual years to an acceptable level, but not so long as to entail bias due to climatic change. Moreover, the period should be as recent as possible, since forecasting is the final objective, and should be as far as possible the same for all stations. The question of finding the period which represents the most satisfactory compromise between these requirements deserves an investigation to itself, but results were wanted quickly, and the 20 years 1921-1940 were chosen, largely because the World Weather Records published by the Smithsonian Institute provide a most convenient source of monthly mean temperature data for years up to 1940.

Synoptic arguments show that the area for which the normals are required must cover at any rate a large part of the Northern Hemisphere, and rather than fix an arbitrary and perhaps erroneous boundary, the analysis was extended to all Northern Hemisphere stations in the World Weather Records which gave enough data, and also to a good many additional stations for which data were obtained from other branches of the Meteorological Office, so as to form as complete a network as possible of stations covering all land areas of the Northern Hemisphere. To avoid having to break isopleths at the coastlines, the analysis was extended to the air temperature at enough points in the oceans to give the run of the isopleths, using data provided by the Marine Branch of the Meteorological Office. The stations used are shown in Fig. 1.

4. The practical calculation

The data were written in vertical columns, and the harmonic analysis carried out using Table 1. Rather over 300 stations were used, the summations of products being carried out on hand operated Friden multipliers. The whole calculation including checking, mostly by repetition, lasted over several months. The phase and amplitude of the first and second harmonics were found. The numerical values are given in Table 6 while Figs. 2 to 8 show the geographical variation of the parameters in a readily assimilable form.

5. The variation of the parameters of the normal temperatures over the Northern Hemisphere

The phase and amplitude of the first and second harmonics of the normal temperature were found from a_1, b_1, a_2, b_2 in the usual way, and charts showing variation over the northern hemisphere of the annual mean a_0 and of A_1, ϕ_1, A_2, ϕ_2 are shown in Figs. 2, 3, 4, 5 and 7. The second harmonic is in most parts of the hemisphere of much smaller amplitude than the first and it is generally better to consider it in relation to the first harmonic instead of by itself. Figs. 6 and 8 present this relation graphically. These figures will be discussed in turn. Only the main points will be mentioned here.

(a) Fig. 2. The yearly mean temperature

This chart is similar to others produced before e.g. in the Oxford Advanced Atlas and is included mainly to provide a basis for interpolation in conjunction with the other charts. The temperatures have not been corrected for altitude, so that due care should be taken in any interpolation between stations at different altitudes. The chart shows clearly the general decrease of annual mean temperature from the equator towards the pole and also the warming effect of proximity to the oceans. On any circle of latitude the lowest temperature occurs over land in the areas most shielded by orography from air blowing across open sea.

(b) Fig. 3. The semi-amplitude of the first harmonic

The semi-amplitude is seen to vary from less than a degree Centigrade in parts of the tropics to over 30 degrees Centigrade in North East Siberia.

The moderating effect of proximity to the sea is seen clearly, particularly on the western borders of the continents. While a small semi-amplitude is characteristic of low latitudes and oceanic regimes, comparatively small values extend far north between Greenland and Norway to Spitzbergen and Nova Zemblya where the seas are ice covered for much of the year. In North America, the moderating influence of the Great Lakes is evident, whereas Hudson Bay seems to have less effect, at any rate on land immediately further west.

(c) Fig.4. The phase of the first harmonic

The isopleths here are at intervals of ten days, and separate stations for which the value of θ , converted into days of a yearly cycle, falls in different periods. That is, they effectively demarcate the hottest part of the summer. It appears that over the interior of the continents the time of highest mean temperature is very uniform, running from 2 to 3 weeks behind the sun. In oceanic stations and on sea coasts the maximum falls later, so that,for example, it is a whole month later in the Azores than in similar latitudes in Turkestan or the Middle West of America. In the subtropics the relative importance of the second harmonic is greater than elsewhere, and the values of ϕ_1 , which do not show much agreement between one region and another, are not readily explicable on the hemispherical scale.

(d) Fig. 5. The semi-amplitude of the second harmonic

The absolute magnitude of this is generally much less than that of the semi-amplitude of the first harmonic, and exceeds 3°C at only one of the stations examined. Most of the larger values occur in the subtropics, but fairly large values also occur in the interior of Russia and at stations bordering the Arctic basin.

(e) Fig. 6. The semi-amplitude of the second harmonic, expressed as a percentage of that of the first

When the relative importance of the second harmonic is expressed as a percentage, there is a sharp contrast between tropical regions, where the percentage amplitude exceeds 30 and temperate regions where it is usually below 20. If we take the 25 per cent value as the dividing line, we find that in Asia it generally lies to south of the main mountain barrier, crosses Egypt and the Sahara, and includes most of the West Indies on the temperate zone, but the mainland of Central America in the tropical. Looking further at the temperature zone, we find that in the interiors of continents, and on eastern seaboards, the ratio is nearly always less than 10 per cent, while in oceanic regions and western seaboards, it generally lies between 10 and 20 per cent.

(f) Fig. 7. The phase of the second harmonic

This is represented by the date of the maximum falling in the first half of the year. The variation of date is usually though not always consistent between adjacent stations: the maximum occurs earlier in certain regions bordering the North Atlantic and North Pacific than elsewhere, but the distribution is not easy to summarise. A more informative presentation is given by Fig. 8.

(g) Fig. 8. The phase of the second harmonic relative to that of the first

This chart shows the number of days up to 91 that the maximum of the second harmonic falls before or after the date of the maximum of the first. If the discrepancy is less than 45 days, the general effect of the second harmonic on the first is to shorten and intensify the maximum and to lengthen and reduce the minimum. That is, it tends to produce a short hot summer and a long rather uniform winter. Where the discrepancy exceeds 45 days these effects are reversed and the tendency is for a long uniform summer and a short cold winter. The one isopleth drawn divides the extratropical world into two regions: one including most of Europe, the Polar basin, Alaska and North Russia, where the

/climate

climate is of the first type and the other region, covering most of North America and Asia, where the climate is of the second type.

These divisions correspond fairly well with those shown on Fig. 6 between the regions where the second harmonic has greater or less relative importance, so that the extra-tropical world is roughly divisible into two regions, namely, one in which the annual temperature variation represented by a pure sine wave is modified considerably in the direction of a short summer and a long winter, and another in which the modification is in the opposite direction, but comparatively slight in amount.

6. The numerical values of the normal temperatures

The parametric form of the temperature normals used in Section 5 is convenient for trying to understand them, but not for showing, for example, how much the observed temperature in Austria on the 14th May is above or below normal. To do this we must have the numerical value on that day. There is no theoretical difficulty in finding the value for a particular day at one place by putting the appropriate values of θ and of the parameters into equation (1) but a table giving daily values for stations covering the Northern Hemisphere would take a long time to prepare, and would be bulky in use. Instead, the calculation was made for every fifth day, starting with January 3rd, for a network of 280 stations covering the hemisphere. For most purposes the normal for one day will be good enough to use for one or two days before or after, and where something better is needed a linear interpolation between normals at 5-day intervals will do. Even with this reduction, over 20,000 calculations are required, and to do these by hand would have absorbed more time and effort than could be spared. Instead the work was sent to the National Physical Laboratory, Teddington for completion by punched card methods, using the 602A calculating punch. The normal temperatures for each station are given in a vertical column with 73 entries to cover the year, 10 stations per page, and 28 pages to cover the 280 stations. In this table the normals for different stations for the same day lie horizontally, thus facilitating the preparation of charts of the normal air temperature for the whole hemisphere for any desired day.

This table has been reproduced photographically and copies can be provided for anyone who would find it useful.

7. The stability of the harmonic parameters

So far we have described the methods by which the normal temperatures were produced. In this section we consider their stability, that is, we examine the way in which the parameters depend on the choice of the period of years on which they are based. We are faced here by a fundamental difficulty, namely that all the quantities to be studied may show, besides the random, or comparatively short term fluctuations which we seek to minimise by choice of basic period, a slow secular variation, or trend. For some variables, for example, the annual mean temperature, such trends are known to be present, and we are certainly not justified in assuming that they do not exist when considering variables such as harmonic coefficients about which very little is known. The analysis of such series requires a detailed and careful investigation, which is already in progress. What are given here are simply some preliminary results, on the assumption that trends may be ignored in the cases considered.

Since each harmonic parameter is a linear function of the twelve monthly mean temperatures, it would be possible, if the latter were uncorrelated, to estimate the variance of the harmonic parameters directly from those of the monthly means. The numerical constants for doing this are given in Table 7, which is used in just the same way as Tables 2 to 5, the monthly mean variances taking the place of the monthly mean temperatures.

/Table 7

Table 7

Monthly mean variance	Multipliers to give variances of:-					
	a_o	a_1	b_1	a_2	b_2	Sum
$V(T_1)$	.0072	.0274	.0021	.0233	.0082	.0682
$V(T_2)$	.0059	.0123	.0118	.0000	.0263	.0563
$V(T_3)$	.0072	.0024	.0271	.0221	.0094	.0682
$V(T_4)$	.0068	.0015	.0261	.0234	.0062	.0640
$V(T_5)$	.0072	.0140	.0154	.0001	.0315	.0682
$V(T_6)$	.0068	.0255	.0022	.0211	.0086	.0642
$V(T_7)$	.0072	.0279	.0017	.0247	.0068	.0683
$V(T_8)$	.0072	.0151	.0144	.0000	.0316	.0683
$V(T_9)$	.0068	.0020	.0257	.0218	.0079	.0642
$V(T_{10})$	.0072	.0019	.0277	.0241	.0075	.0684
$V(T_{11})$	.0068	.0136	.0140	.0000	.0298	.0642
$V(T_{12})$	.0072	.0274	.0021	.0233	.0082	.0682

The practical value of the calculation is, however, reduced by two things, (1) for very few stations have we reliable estimates of the variances of the monthly mean temperatures, and in any case, such estimates may contain an element due to trend and (2) in fact the temperature anomalies in consecutive months are not unrelated, but show a positive correlation. However, for two stations, Kew and Prague, the variances have been calculated from many years data, and estimates of the variances of the harmonic parameters, using Table 7, are given in Table 8.

Table 8

	Variances of monthly mean temperatures	
	Kew 1871-1950 $^oF^2$	Prague 1775-1938 $^oC^2$
J	11.78	10.14
F	11.88	8.39
M	6.35	5.24
A	4.59	3.65
M	4.63	3.48
J	3.49	2.43
J	5.63	2.25
A	5.19	2.23
S	4.80	2.24
O	5.93	2.54
N	6.51	3.43
D	10.90	8.43
	Variances of harmonic coefficients for single years derived from the above	
a_o	0.56	0.38
a_1	1.29	0.89
b_1	1.02	0.65
a_2	1.24	0.85
b_2	1.24	0.80

It appears that the variance of any harmonic parameter is only 40 or 50 per cent of the variance in the most uniform month of the year, and less than 10 per cent of the variance in the most variable month. The existence of

serial correlations between the temperature anomalies in consecutive months means that these estimates have to be increased somewhat: if the correlations are about 0.3, a reasonable estimate, the increase will be about 10 per cent.

If the departures of the harmonic coefficients in a given year from their mean values are uncorrelated, then the values in Table 8 can be used to estimate the variance of the estimate of the normal temperature for a particular day or period obtained by harmonic synthesis. The estimate will be about twice the variance of the individual harmonic coefficients (since $\sin^2\theta + \cos^2\theta = 1$) or about 2.4 $^{\circ}F^2$ for Kew and 1.5 $^{\circ}C^2$ for Prague. To these have to be added the variance of a_o, giving totals of about 3 $^{\circ}F^2$ for Kew and 2 $^{\circ}C^2$ for Prague. The presence of serial correlations and trends will tend to increase these values, but even allowing for this the true values must be less than most of the monthly variances given in Table 8.

Thus the process of estimating normal temperatures by harmonic analysis followed by harmonic synthesis, if used to produce a monthly normal, appears to give a more accurate estimate than the mean temperatures for that month on which the calculation is based.

The above conclusions are only regarded as provisional, pending the completion of the investigation into the points on which reasonable assumptions have been made in the above argument. However, if we accept the numerical estimates as correct, we can make the following estimates of the uncertainty attaching to normal temperatures found in this way from data averaged over 20 or 30 years.

Table 9

	Variance	S.D.
For one year	3.0	1.73
For 20 year mean	0.15	0.38
For 30 year mean	0.10	0.32
For difference between 20 year mean, and mean for 30 years containing the first 20 years	0.05	0.23

Table 9 assumes the variance for a single year to have the value estimated for Kew. For stations where this is true, the normal temperature estimated from our 20 years basic period will generally (about 95 per cent of the time) be within 0.8°F of the true value, while the estimate based on our data will usually be within 0.5°F of a similar estimate based on data for the internationally agreed period 1921-1950. Elsewhere the confidence limits will be correspondingly greater or less, depending on the variance for the estimate based on a single year. These uncertainties are far less than the daily anomalies of temperature which are to be investigated, using these normals, so the results of this section, which are admittedly only provisional, suggest that the normals are quite accurate enough for the purpose for which they are intended.

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Table 6

Numerical values of harmonic coefficients at stations in Northern Hemisphere

No.	Station	a_0	a_1	b_1	A_1	ϕ_1	a_2	b_2	A_2	ϕ_2
1	Akureyri	4.76	-6.70	-2.40	7.12	21/7	1.03	0.31	1.08	9/1
2	Stykkisholm	4.51	-5.61	-2.17	6.01	23/7	0.82	0.65	1.05	20/1
3	Teigarhorn	5.08	-5.29	-1.83	5.60	21/7	0.75	0.72	1.04	23/1
4	Reykjavik	5.03	-5.27	-1.88	5.60	21/7	0.75	0.68	1.01	22/1
5	Vestmannaeyjar	5.83	-4.17	-1.69	4.50	24/7	0.66	0.69	0.95	24/1
6	Horta	17.47	-2.82	-2.93	4.07	17/8	0.12	0.79	0.80	11/2
7	Ponta Delgada	17.47	-2.54	-2.74	3.74	18/8	0.07	0.68	0.68	12/2
8	Funchal	18.80	-2.14	-2.52	3.31	21/8	-0.29	0.38	0.48	6/3
9	St. Vincent	23.82	-0.93	-2.26	2.44	8/9	-0.49	-0.08	0.50	6/4
10	Santiago	24.97	-1.17	-1.97	2.29	31/8	-0.42	-0.25	0.49	17/4
11	Freetown	26.37	0.61	0.79	1.00	23/2	-0.31	-0.42	0.52	29/4
12	Thorshavn	6.59	-2.87	-2.03	3.52	6/8	0.59	0.60	0.84	24/1
13	Bergen	7.60	-5.83	-2.55	6.36	25/7	0.55	0.53	0.76	23/1
14	Aberdeen	8.28	-4.52	-2.31	5.08	29/7	0.44	0.78	0.90	31/1
15	Edinburgh	8.67	-5.08	-2.32	5.59	26/7	0.50	0.79	0.93	30/1
16	Valentia	10.78	-3.67	-2.01	4.18	31/7	0.32	0.52	0.61	30/1
17	Greenwich	10.17	-6.13	-2.49	6.62	24/7	0.44	0.75	0.87	1/2
18	De Bilt	10.28	-8.15	-2.46	8.51	19/7	0.09	0.44	0.45	9/2
19	Frankfurt	10.08	-8.78	-2.23	9.06	16/7	-0.02	0.52	0.52	16/2
20	Paris	11.04	-7.45	-2.28	7.79	19/7	0.07	0.81	0.81	13/2
21	Nantes	11.63	-6.40	-2.45	6.85	23/7	-0.01	0.87	0.87	16/2
22	Lyon	11.31	-8.47	-2.82	8.93	20/7	-0.17	0.78	0.80	21/2
23	Zurich	8.82	-8.82	-2.43	9.15	17/7	-0.21	0.31	0.37	4/3
24	Milan	13.34	-10.70	-3.10	11.14	18/7	-0.38	0.65	0.75	2/3
25	Corunna	13.48	-4.02	-2.53	4.75	3/8	-0.35	0.64	0.73	2/3
26	Saragossa	14.26	-8.28	-2.98	8.80	22/7	-0.42	1.12	1.20	26/2
27	Barcelona	16.54	-6.52	-3.44	7.37	30/7	-0.24	0.92	0.95	23/2
28	Madrid	13.57	-8.83	-3.29	9.42	22/7	-0.18	1.59	1.60	18/2
29	Palma	16.46	-6.42	-3.84	7.48	2/8	-0.20	0.92	0.94	21/2
30	Lisbon	15.93	-4.86	-2.74	5.58	31/7	-0.41	0.92	1.01	27/2
31	Alicante	17.56	-5.87	-3.28	6.72	31/7	-0.39	0.93	1.01	27/2
32	Seville	18.31	-7.86	-3.58	8.64	26/7	-0.42	1.42	1.48	23/2
33	Gibraltar	17.37	-4.66	-3.00	5.54	4/8	-0.16	0.86	0.87	20/2
34	Bouzaréah	16.21	-5.85	-3.77	6.96	4/8	-0.22	0.87	0.90	22/2
35	Accra	26.63	0.98	1.16	1.52	20/2	-0.16	-0.68	0.70	10/5
36	Lagos	27.01	0.84	1.06	1.35	22/2	-0.42	-0.36	0.56	22/4
37	Calabar	25.16	0.29	0.71	0.77	10/3	-0.35	-0.42	0.55	27/4
38	Spitsbergen	-4.57	-7.63	-6.41	9.97	11/8	1.80	0.50	1.87	8/1
39	Stetnes	1.90	-6.08	-3.68	7.11	2/8	1.04	0.97	1.42	22/1
40	Bodo	5.09	-6.70	-3.23	7.44	28/7	1.06	0.91	1.40	21/1
41	Haparanda	1.81	-11.83	-4.85	12.79	24/7	1.62	0.21	1.63	4/1
42	Oslo	6.42	-9.78	-3.05	10.25	19/7	0.75	0.35	0.83	13/1
43	Uppsala	5.70	-9.80	-3.58	10.44	22/7	1.18	0.33	1.23	8/1
44	Helsinki	5.32	-10.40	-4.60	11.37	26/7	1.10	-0.04	1.10	11/5
45	Copenhagen	8.32	-7.96	-3.45	8.67	25/7	0.68	0.22	0.71	10/1
46	Konigsberg	7.36	-9.68	-3.64	10.34	22/7	0.22	-0.22	0.31	9/6
47	Vilna	6.48	-11.52	-3.44	12.02	18/7	0.09	-0.78	0.79	20/5
48	Berlin	9.41	-9.14	-2.70	9.53	18/7	0.08	0.30	0.32	8/2
49	Potsdam	8.73	-9.19	-2.77	9.60	18/7	0.06	0.27	0.28	9/2
50	Warsaw	8.16	-10.62	-3.11	11.07	18/7	0.00	-0.38	0.38	17/5

No.	Station	a_0	a_1	b_1	A_1	ϕ_1	a_2	b_2	A_2	ϕ_2
51	Breslau	8.74	-9.69	-2.80	10.08	18/7	-0.11	0.04	0.12	23/3
52	Cernauti	8.09	-11.97	-3.48	12.47	18/7	0.64	-0.79	1.02	6/6
53	Vienna	9.70	-9.88	-2.77	10.26	17/7	-0.21	0.09	0.23	21/3
54	Sonnblick	-5.98	-6.64	-3.53	7.52	30/7	0.34	0.17	0.38	14/1
55	Obir	0.74	-7.45	-3.74	8.34	29/7	0.28	0.35	0.45	27/1
56	Sibiu	9.02	-11.32	-3.01	11.71	17/7	-0.99	-0.49	1.11	15/4
57	Padua	12.83	-10.18	-3.14	10.65	19/7	-0.46	0.36	0.58	13/3
58	Modena	13.50	-11.27	-2.91	11.64	16/7	-0.73	0.78	1.07	9/3
59	Belgrade	11.74	-10.87	-3.21	11.33	18/7	-0.87	-0.27	0.91	10/4
60	Bucharest	11.10	-12.43	-3.79	13.00	19/7	-1.14	-0.50	1.25	14/4
61	Sulina	11.16	-10.95	-4.47	11.83	24/7	-0.09	-0.44	0.45	11/5
62	Sofia	10.59	-10.96	-3.42	11.48	19/7	-0.89	-0.11	0.90	4/4
63	Plovdiv	12.71	-11.08	-3.50	11.62	19/7	-0.56	0.08	0.57	29/3
64	Vigna di Valle	14.26	-7.69	-3.81	8.58	28/7	0.11	0.73	0.74	11/2
65	Naples	16.13	-7.27	-3.15	7.92	25/7	0.02	0.31	0.31	13/2
66	Corfu	18.43	-7.47	-3.91	8.43	30/7	0.06	0.60	0.60	12/2
67	Salonika	16.27	-9.70	-4.16	10.56	25/7	-0.17	0.26	0.31	4/3
68	Riposto	17.95	-6.38	-4.48	7.79	6/8	-0.54	1.00	1.14	2/3
69	Sparta	17.98	-9.15	-4.00	9.99	25/7	0.14	0.73	0.74	10/2
70	Heraklion	19.66	-6.44	-3.69	7.42	1/8	-0.06	0.14	0.15	27/2
71	Malta	18.39	-5.59	-4.36	7.09	9/8	0.60	0.47	0.76	20/1
72	Cyrene	15.83	-6.11	-3.53	7.06	1/8	-0.27	-0.61	0.67	5/5
73	Agedabia	21.00	-6.30	-2.54	6.79	24/7	-0.92	-0.92	1.30	24/4
74	Alexandria	20.90	-4.86	-3.70	6.11	8/8	-0.62	-0.25	0.67	13/4
75	Archangel	1.59	-12.97	-5.24	13.99	24/7	1.09	-0.03	1.09	11/5
76	Leningrad	4.84	-12.17	-4.52	12.98	22/7	0.81	-0.32	0.87	21/6
77	Moscow	4.37	-14.07	-4.27	14.70	19/7	0.15	-1.07	1.08	21/5
78	Kasan	4.24	-16.33	-4.67	16.99	18/7	0.02	-1.05	1.05	18/5
79	Nikolaevskoe	4.57	-16.98	-5.17	17.75	19/7	-0.02	-1.47	1.47	17/5
80	Astrachan U.S.S.R.	9.61	-15.83	-4.83	16.55	19/7	0.07	-1.11	1.11	19/5
81	Novorrossisk	13.03	-9.86	-4.88	11.00	28/7	0.33	0.05	0.34	5/1
82	Beirut	21.60	-6.30	-4.21	7.58	5/8	-0.58	0.01	0.58	1/4
83	Ramleh	21.56	-6.24	-3.84	7.33	3/8	-0.72	-0.72	1.02	24/4
84	Amman	18.71	-8.87	-4.02	9.74	26/7	-1.17	-0.67	1.35	17/4
85	Heliopolis	23.09	-7.60	-2.69	8.06	21/7	-0.76	-0.80	1.10	25/4
86	Helwan	21.83	-7.08	-2.81	7.62	23/7	-0.79	-0.76	1.10	24/4
87	Khartoum	29.56	-4.26	-0.52	4.29	9/7	-1.60	-2.00	2.56	28/4
88	Aden	28.75	-3.21	-0.80	3.31	16/7	-0.31	-0.68	0.75	5/5
89	Kampala	21.00	0.80	0.33	0.87	23/1	-0.04	0.07	0.08	2/3
90	Entebbe	21.47	0.51	0.31	0.60	1/2	-0.20	-0.07	0.21	11/4
91	Malye Karmakouly	-4.35	-8.13	-6.78	10.59	11/8	1.75	1.05	2.04	16/1
92	Waigatz	-5.60	-8.78	-8.00	11.88	13/8	0.99	0.30	1.03	9/1
93	Ust-Zylma	-1.31	-14.13	-5.20	15.06	22/7	0.75	0.24	0.79	9/1
94	Berezov	-3.08	-17.45	-6.03	18.46	21/7	0.00	0.72	0.72	15/2
95	Perm	2.09	-16.41	-4.33	16.97	16/7	-0.11	-0.68	0.69	12/5
96	Sverdlovsk	1.76	-16.34	-4.11	16.85	16/7	-0.28	-0.83	0.88	8/5
97	Tobolsk	0.63	-17.74	-4.60	18.32	16/7	-0.58	-0.50	0.77	22/4
98	Orenburg	4.35	-18.73	-5.48	19.51	18/7	-0.13	-1.65	1.65	15/5
99	Turgai	4.90	-20.54	-6.32	21.49	19/7	-0.18	-2.06	2.07	15/5
100	Fort Uritsky	11.49	-13.90	-5.33	14.89	23/7	0.05	-0.48	0.48	20/5

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No.	Station	a_o	a_1	b_1	A_1	ϕ_1	a_2	b_2	A_2	ϕ_2
101	Kasalinsk	8.18	-18.78	-4.54	19.32	15/7	-0.67	-1.54	1.68	5/5
102	Krasnovodsk	15.72	-12.54	-5.04	13.52	24/7	-0.25	0.36	0.44	5/3
103	Tashkent	13.37	-13.57	-2.78	13.85	13/7	-0.32	-0.06	0.33	7/4
104	Bushire	24.19	-8.28	-3.65	9.05	26/7	-1.03	-0.33	1.08	11/4
105	Quetta	14.87	-11.04	-2.37	11.29	14/7	-0.20	0.54	0.58	25/2
106	Kalat	13.42	-10.57	-2.49	10.86	15/7	0.18	0.16	0.24	22/1
107	Karachi	25.48	-4.70	-0.93	4.79	13/7	-0.87	-1.28	1.55	30/4
108	Dickson	-10.75	-13.53	-8.57	16.02	3/8	0.57	1.17	1.30	2/2
109	Turukhansk	-6.32	-20.01	-6.37	21.00	19/7	-0.55	2.21	2.28	22/2
110	Surgut	-2.48	-18.23	-5.79	19.12	19/7	-0.16	0.42	0.45	26/2
111	Omsk	0.85	-18.88	-5.58	19.69	18/7	-0.45	-1.50	1.57	9/5
112	Tomsk	-0.15	-18.26	-5.08	18.96	17/7	-0.52	-0.38	0.64	20/4
113	Barnard	1.55	-18.68	-5.28	19.41	18/7	-0.38	-1.21	1.27	8/5
114	Akmolinsk	1.70	-19.16	-5.51	19.93	18/7	-0.22	-1.46	1.48	13/5
115	Alma Ata	8.84	-15.00	-3.84	15.48	16/7	-1.17	-0.13	1.18	5/4
116	Naryn	2.69	-16.28	-4.28	16.83	16/7	-2.82	-1.29	3.10	14/4
117	Leh	5.72	-11.43	-3.73	12.02	20/7	-1.19	0.22	1.21	27/3
118	Lahore	24.51	-10.72	-1.45	10.82	9/7	-1.69	-1.11	2.02	18/4
119	Allahabad	26.08	-8.17	0.84	8.21	26/6	-2.16	-1.93	2.90	23/4
120	Nagpur	26.82	-5.02	2.48	5.60	5/6	-2.04	-1.89	2.78	23/4
121	Calcutta	26.59	-4.93	0.51	4.96	26/6	-2.46	-0.77	2.58	10/4
122	Bombay	27.31	-1.82	0.08	1.82	29/6	-0.81	-1.46	1.67	2/5
123	Vizagapatam	27.38	-3.34	0.17	3.34	29/6	-1.06	-0.62	1.23	17/4
124	Bangalore	24.01	-1.64	1.79	2.43	15/5	-1.58	-0.53	1.67	11/4
125	Hambantota	26.96	-0.88	0.10	0.89	25/6	-0.28	-0.09	0.31	11/4
126	Yenisseysk	-1.74	-19.51	-5.18	20.18	17/7	-0.94	-0.04	0.94	3/4
127	Kirensk	-3.18	-21.75	-5.09	22.34	15/7	-1.38	0.14	1.39	30/3
128	Minusinsk	0.40	-19.87	-5.41	20.59	17/7	-0.92	-1.32	1.61	29/4
129	Irkutsk	-0.88	-19.04	-4.57	19.58	15/7	-1.28	-0.38	1.33	10/4
130	Shillong	16.56	-5.68	-0.73	5.73	9/7	-1.57	-0.01	1.57	2/4
131	Yunnanfu	15.89	-5.92	-0.91	5.99	10/7	-0.92	-0.17	0.94	7/4
132	Mandalay	27.53	-4.40	0.44	4.42	26/6	-2.30	-0.94	2.49	13/4
133	Rangoon	27.56	-0.64	0.70	0.95	15/5	-1.28	-0.71	1.46	16/4
134	Port Blair	27.44	-0.42	0.53	0.68	11/5	-0.50	-0.46	0.68	23/4
135	Singapore	27.12	-0.62	0.05	0.62	27/6	0.14	0.00	0.14	2/7
136	Olekminsk	-5.83	-24.94	-5.96	25.64	15/7	-1.22	0.24	1.24	27/3
137	Yakutsk	-9.81	-30.27	-6.82	31.03	14/7	-2.26	-0.21	2.27	4/4
138	Tchita	-2.38	-21.82	-4.79	22.34	14/7	-1.90	-0.51	1.97	9/4
139	Nerchinsky Zavod	-3.17	-23.50	-5.11	24.05	14/7	-2.48	-0.54	2.54	8/4
140	Blagovyestchensk	0.33	-22.30	-5.40	22.94	15/7	-2.10	-0.04	2.10	2/4
141	Tientsin	12.18	-15.26	-3.81	15.73	16/7	-1.23	-0.17	1.24	5/4
142	Joshin	8.10	-11.56	-6.32	13.17	31/7	-1.56	0.68	1.70	21/3
143	Chempulo	10.80	-12.91	-5.89	14.19	26/7	-1.30	0.18	1.31	29/3
144	Hankow	17.46	-12.18	-4.34	12.93	16/7	-1.02	0.02	1.02	1/4
145	Nanking	15.53	-12.10	-4.62	12.95	23/7	-0.74	0.06	0.74	30/3
146	Shanghai	15.55	-10.89	-5.00	11.98	26/7	-0.42	0.22	0.47	19/3
147	Nagasaki	15.45	-9.23	-4.94	10.47	30/7	-0.36	0.41	0.55	8/3
148	Hong Kong	22.40	-5.95	-3.12	6.72	30/7	-0.34	-0.85	0.92	6/5
149	Naha	21.88	-5.20	-3.22	6.12	3/8	-0.08	-0.03	0.09	12/4
150	Legaspi	27.16	-0.99	0.13	1.00	24/6	-0.29	-0.46	0.54	1/5

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No.	Station	a_0	a_1	b_1	A_1	ϕ_1	a_2	b_2	A_2	ϕ_2
151	Sandakan	27.35	-0.51	-0.12	0.52	15/7	-0.19	-0.16	0.25	22/4
152	Verkhoyansk	-14.56	-31.94	-6.88	32.67	14/7	-1.32	0.09	1.32	31/3
153	Ust Mayskoe	-8.98	-29.40	-6.54	30.12	14/7	-2.92	-0.74	3.01	9/4
154	Okhotsk	-4.37	-16.49	-6.49	17.72	23/7	-1.96	1.20	2.30	17/3
155	Nikolaeyevsk-on-Amur	-2.05	-18.61	-7.64	20.12	24/7	-1.87	0.39	1.91	27/3
156	Ochiai	2.22	-12.96	-7.23	14.84	31/7	-1.48	-0.14	1.49	4/4
157	Nikolsk Ussuriysky	2.81	-19.01	-6.54	20.10	21/7	-3.40	-0.35	3.42	4/4
158	Nemuro	5.74	-8.43	-7.03	10.97	11/8	-1.15	-0.02	1.15	2/4
159	Vladivostok	4.25	-14.80	-6.78	16.28	26/7	-2.99	0.36	3.01	29/3
160	Miyako	10.13	-9.69	-5.75	11.27	2/8	-0.68	0.53	0.86	14/3
161	Kyoto	14.13	-10.74	-5.37	12.01	28/7	-0.15	0.60	0.62	22/2
162	Tokyo	14.21	-9.95	-5.24	11.24	30/7	-0.50	0.47	0.69	11/3
163	Omura	22.67	-3.97	-3.82	5.51	15/8	-0.49	-0.20	0.53	13/4
164	Guam	27.53	-0.56	0.03	0.56	29/6	-0.09	-0.44	0.45	11/5
165	Petropavlovsk	1.08	-8.82	-5.37	10.33	2/8	-0.73	1.07	1.30	5/3
166	34°N.162°E.	18.43	-3.10	-4.71	5.64	28/8	-0.43	1.02	1.11	27/2
167	Novo-Marinsky Post	-7.30	-14.69	-7.97	16.71	30/7	1.60	1.53	2.21	23/1
168	St. Paul Is.	1.99	-4.84	-4.26	6.45	12/8	0.34	0.31	0.46	22/1
169	32°N.178°E.	20.65	-3.38	-3.61	4.95	18/8	0.20	0.47	0.51	3/2
170	Midway Is.	21.99	-3.12	-2.61	4.07	11/8	-0.03	0.08	0.09	26/2
171	Barrow	-12.13	-14.90	-8.29	17.05	31/7	1.40	-0.17	1.41	28/6
172	Nome	-3.10	-12.12	-5.56	13.33	26/7	0.58	0.28	0.64	14/1
173	Tanana	-4.13	-19.33	-4.29	19.80	14/7	-0.07	-0.16	0.17	5/5
174	Kodiak	5.32	-5.86	-3.25	6.70	31/7	0.27	0.97	1.01	7/2
175	Dutch Harbour	4.79	-4.93	-3.18	5.87	4/8	0.19	1.06	1.08	10/2
176	Honolulu	23.92	-1.28	-1.42	1.91	19/8	-0.09	0.01	0.09	30/3
177	Aklavik	-9.35	-20.31	-7.52	21.66	22/7	0.83	0.84	1.18	23/1
178	Fairbanks	-3.47	-20.16	-3.86	20.53	12/7	-1.32	-0.52	1.42	12/4
179	Dawson	-4.82	-21.59	-4.72	22.10	14/7	-1.50	-1.12	1.87	20/4
180	Valdez	2.04	-8.92	-3.21	9.48	22/7	-0.35	0.11	0.37	24/3
181	Juneau	5.81	-7.30	-2.77	7.81	23/7	0.09	0.17	0.20	1/2
182	Sitka	6.98	-5.69	-2.85	6.36	28/7	-0.03	0.60	0.60	17/2
183	Massett	7.69	-5.19	-2.95	5.97	1/8	-0.04	0.64	0.64	17/2
184	Prince Rupert	7.69	-5.42	-2.60	6.01	27/7	-0.30	0.47	0.56	4/3
185	Ft.Good Hope	-8.01	-23.06	-6.74	24.02	18/7	0.43	-0.21	0.48	19/6
186	Coppermine	-11.43	-18.42	-8.85	20.43	28/7	1.06	1.42	1.77	27/1
187	Ft.Simpson	-3.62	-21.40	-6.07	22.25	18/7	-1.43	-0.98	1.73	19/4
188	Hay River	-4.34	-18.98	-7.70	20.48	24/7	-1.05	-0.37	1.11	11/4
189	Ft. Smith	-3.43	-20.28	-6.11	21.18	18/7	-1.19	-1.34	1.79	26/4
190	Ft. McMurray	-1.01	-18.86	-4.67	19.43	16/7	-2.29	-1.09	2.54	14/4
191	Bella Coola	7.58	-8.51	-2.51	8.87	18/7	-0.56	0.43	0.71	14/3
192	Prince George	4.13	-11.98	-3.23	12.41	17/7	-1.20	-0.37	1.26	10/4
193	Barkerville	1.77	-10.22	-2.88	10.61	17/7	-0.27	0.25	0.37	11/3
194	Edmonton	2.73	-14.82	-3.81	15.30	16/7	-1.27	-0.76	1.48	17/4
195	Calgary	4.05	-12.53	-3.81	13.10	19/7	-0.43	-0.16	0.46	12/4
196	Victoria	10.07	-5.33	-2.04	5.71	23/7	-0.40	0.34	0.53	12/3
197	Spokane	9.47	-11.39	-3.10	11.80	17/7	-0.40	1.05	1.12	26/2
198	Helena	7.14	-12.33	-3.76	12.89	19/7	-0.13	0.84	0.85	20/2
199	Portland	12.18	-7.33	-2.57	7.77	21/7	-0.61	0.74	0.96	7/3
200	Red Bluff	16.91	-9.30	-3.17	9.83	21/7	-0.25	1.06	1.09	22/2

/201

No.	Station	a_o	a_1	b_1	A_1	ϕ_1	a_2	b_2	A_2	ϕ_2
201	Salt Lake City	11.63	-12.83	-4.01	13.45	19/7	-0.21	1.23	1.25	20/2
202	San Francisco	13.59	-1.93	-1.42	2.40	7/8	-1.22	-0.34	1.27	9/4
203	Sacramento	16.42	-7.78	-2.74	8.25	21/7	-0.93	0.77	1.21	13/3
204	Modena (U.S.A.)	9.12	-11.87	-3.69	12.43	19/7	-0.53	1.26	1.37	27/2
205	San Diego	16.52	-3.01	-2.10	3.67	6/8	-0.33	0.52	0.62	4/3
206	Phoenix	21.66	-10.55	-3.38	11.08	20/7	-0.35	1.17	1.22	24/2
207	Chesterfield Inlet	-11.74	-19.09	-9.74	21.43	29/7	-0.09	0.36	0.37	22/2
208	Churchill	-7.42	-18.70	-8.93	20.72	27/7	-0.68	0.42	0.80	17/3
209	Prince Albert	1.47	-17.66	-5.13	18.39	18/7	-1.44	-1.03	1.77	20/4
210	The Pas	-0.18	-19.28	-5.89	20.16	19/7	-1.24	-0.87	1.51	19/4
211	Qu' Appelle	2.39	-16.50	-4.99	17.23	19/7	-1.15	-0.68	1.34	17/4
212	Winnipeg	2.76	-17.98	-5.83	18.90	20/7	-1.33	-0.88	1.59	18/4
213	Bismarck	5.90	-16.29	-4.90	17.01	18/7	-0.92	-0.18	0.94	7/4
214	Minneapolis	7.46	-15.81	-4.97	16.57	19/7	-1.00	-0.34	1.06	11/4
215	Cheyenne	7.46	-11.23	-4.42	12.06	23/7	0.50	0.98	1.10	1/2
216	Denver	10.66	-11.33	-3.97	12.00	21/7	0.31	1.02	1.07	7/2
217	North Platte	10.35	-13.84	-4.17	14.45	18/7	-0.38	0.90	0.98	27/2
218	Omaha	11.23	-14.64	-4.47	15.31	19/7	-0.87	0.17	0.89	27/3
219	St. Louis	13.99	-12.61	-4.16	13.28	20/7	-0.60	0.47	0.76	13/3
220	Sata Fe	9.56	-10.85	-3.41	11.37	19/7	-0.45	0.66	0.80	5/3
221	El Paso	17.92	-10.57	-2.53	10.86	15/7	-0.62	0.53	0.82	12/3
222	Abilene	18.30	-10.74	-3.03	11.16	17/7	-0.93	0.74	1.19	13/3
223	Little Rock	16.94	-10.69	-3.36	11.21	19/7	-0.77	0.68	1.03	12/3
224	Galveston	21.10	-7.65	-3.07	8.24	24/7	-0.78	0.23	0.81	24/3
225	Corpus Christi	22.00	7.11	-2.56	7.56	22/7	-1.08	0.16	1.09	28/3
226	Monterrey	21.79	-6.63	-1.01	6.71	10/7	-1.04	0.28	1.08	25/3
227	Mazatlan	23.74	-3.45	-3.15	4.67	13/8	-0.25	-0.26	0.36	25/4
228	Leon	18.86	-3.32	0.64	3.38	21/6	-1.02	-0.84	1.32	22/4
229	Tacubaya	14.73	-2.27	0.67	2.37	15/6	-0.93	-0.29	0.97	10/4
230	Mexico City	16.51	-2.05	0.72	2.17	12/6	-0.86	-0.32	0.92	12/4
231	Puebla	16.25	-2.28	0.56	2.35	18/6	-1.01	-0.38	1.08	12/4
232	Oaxaca	20.21	-1.86	0.89	2.06	6/6	-0.92	-0.28	0.96	10/4
233	Nottingham Is.	-8.98	-14.29	-7.91	16.33	31/7	-0.52	-0.97	1.10	3/5
234	Moosonee	-1.72	-16.82	-7.47	18.40	26/7	-0.86	-0.62	1.06	20/4
235	Mistassini Post	-1.55	-16.30	-7.09	17.78	25/7	-0.95	-0.98	1.37	25/4
236	Chicoutimi	3.00	-16.16	-6.19	17.30	23/7	-1.31	-0.56	1.43	13/4
237	Marquette	5.50	-12.31	-5.69	13.56	27/7	-0.21	0.09	0.23	21/3
238	Toronto	8.30	-12.19	-5.20	13.25	25/7	0.23	-0.01	0.23	30/6
239	Montreal	6.42	-14.46	-5.53	15.48	23/7	-0.32	-0.69	0.76	5/5
240	Chicago	10.45	-12.35	-5.14	13.37	24/7	-0.54	0.40	0.67	14/3
241	Detroit	9.74	-12.57	-5.07	13.56	24/7	0.08	0.16	0.18	2/2
242	New York	11.49	-10.82	-4.73	11.81	25/7	-0.04	0.06	0.07	4/3
243	Albany	9.30	-12.57	-4.76	13.45	23/7	-0.12	-0.28	0.30	5/5
244	New Haven	10.44	-11.13	-4.69	12.08	25/7	-0.09	0.11	0.14	7/3
245	Cincinnati	13.20	-11.81	-4.09	12.50	21/7	-0.39	0.29	0.49	14/3
246	Washington D.C.	13.52	-11.13	-3.88	11.79	21/7	-0.15	0.30	0.34	1/3
247	Nashville	15.49	-10.74	-3.47	11.29	20/7	-0.52	0.56	0.76	9/3
248	Hatteras	17.08	-8.20	-3.83	9.05	27/7	-0.19	0.31	0.36	3/3
249	Charleston	18.95	-8.26	-2.83	8.73	21/7	-0.46	0.39	0.60	12/3
250	Mobile	19.67	-7.99	-2.57	8.39	20/7	-0.58	0.46	0.74	13/3
251	Key West	25.20	-3.54	-1.60	3.88	26/7	-0.40	0.21	0.45	19/3
252	Havana	24.87	-2.48	-1.14	2.73	27/7	-0.32	0.08	0.33	26/3
253	Merida	25.81	-2.45	-0.02	2.45	2/7	-0.70	-0.17	0.72	8/4
254	Negril Pt. Lighthouse	25.91	-1.07	-0.89	1.39	11/8	-0.02	-0.25	0.25	15/5
255	Kingston	26.22	-1.47	-0.54	1.57	22/7	0.11	-0.31	0.33	27/5

No.	Station	a_o	a_1	b_1	A_1	ϕ_1	a_2	b_2	A_2	ϕ_2
256	Port-au-Prince	26.48	-1.44	-0.53	1.53	22/7	-0.03	0.02	0.04	16/3
257	San Salvador	23.17	-0.62	0.42	0.75	28/5	-0.34	-0.10	0.35	10/4
258	Colon	27.35	-0.30	0.21	0.37	28/5	-0.15	0.01	0.15	31/3
259	Uppernivik	-6.12	-10.66	-7.21	12.87	5/8	1.44	-1.41	2.01	9/6
260	Jacobshavn	-3.40	-10.09	-4.26	10.95	25/7	1.02	-0.24	1.05	25/6
261	Godthaab	-0.43	-7.71	-3.27	8.37	25/7	0.34	0.20	0.39	16/1
262	Resolution Is.	-6.16	-9.48	-6.09	11.27	4/8	-0.82	-1.49	1.70	3/5
263	Father Point	2.12	-12.10	-5.16	13.15	25/7	-0.78	-0.83	1.14	25/4
264	Anticosti	1.82	-10.41	-5.92	10.21	1/8	-0.45	-0.37	0.58	21/4
265	Natashquan	0.57	-12.94	-6.36	14.42	28/7	-0.92	-0.56	1.08	17/4
266	Eastport	5.52	-9.50	-5.06	10.76	30/7	-0.75	-0.21	0.78	9/4
267	Charlottetown	5.75	-11.82	-6.52	13.50	31/7	-0.11	-0.18	0.21	1/5
268	Cape Race	4.34	-6.98	-5.77	9.06	11/8	-0.38	0.31	0.49	13/3
269	St. Johns	4.97	-8.90	-5.90	10.68	4/8	0.17	0.21	0.27	26/1
270	Sable Island	7.11	-6.85	-6.53	9.46	15/8	-0.36	0.71	0.80	1/3
271	42°N. 62°W.	11.09	-7.46	-6.25	9.73	11/8	0.38	0.56	0.68	29/1
272	Bermuda (St. George)	21.43	-3.87	-3.36	5.13	12/8	0.18	0.46	0.49	4/2
273	32°N. 52°W.	22.16	-2.53	-3.26	4.13	23/8	0.20	0.44	0.48	3/2
274	San Juan	25.49	-1.23	-1.16	1.69	14/8	-0.10	-0.23	0.25	25/4
275	Trinidad	26.41	-0.68	-0.33	0.76	28/7	-0.26	-0.58	0.64	5/5
276	Georgetown	26.99	-0.15	-0.43	0.46	11/9	-0.41	-0.22	0.47	16/4
277	Ivigtut	1.54	-7.50	-2.62	7.95	21/7	0.38	-0.02	0.38	30/6
278	Angmagssalik	-0.66	-6.85	-2.42	7.27	21/7	1.10	0.46	1.19	12/1
279	55°N. 35°W.	7.74	-2.72	-1.69	3.20	3/8	-0.63	0.69	0.93	9/3
280	42°N. 42°W.	13.16	-4.93	-3.41	5.99	6/8	0.06	0.42	0.42	11/2
281	Peshawar	22.64	-11.11	-2.87	11.48	16/7	-0.44	-0.59	0.74	29/4
282	Simla	13.06	-6.81	-1.06	6.89	11/7	-0.80	-1.55	1.75	3/5
283	New Delhi	24.81	-9.37	-0.64	9.39	5/7	-1.79	-1.71	2.48	24/4
284	Jaipur	25.60	-7.94	0.25	7.95	30/6	-1.85	-1.93	2.67	25/4
285	Madras	28.47	-3.93	0.20	3.93	29/6	-0.32	-0.66	0.73	4/5
286	Amini Divi	28.11	-0.23	0.97	1.00	15/4	-0.58	-0.48	0.75	22/4
287	Minicoy	27.74	-4.68	0.69	4.73	24/6	-0.52	-0.41	0.66	21/4
288	Cochin	27.09	0.30	1.08	1.12	17/3	-0.67	-0.43	0.80	18/4
289	Kodaikanal	14.59	-1.32	0.85	1.57	30/5	-0.75	-0.35	0.83	14/4
290	Trincomalee	27.75	-2.25	-0.10	2.25	4/7	-0.36	-0.07	0.37	7/4
291	Nuwara Eliya	15.25	-0.89	-0.15	0.90	11/7	-0.22	-0.57	0.61	6/5
292	Colombo	26.86	-0.67	0.30	0.73	8/6	-0.28	-0.14	0.31	15/4
293	Akyab	25.62	-2.85	-0.28	2.86	7/7	-1.79	-1.18	2.14	18/4
294	Mergui	26.59	-0.39	0.69	0.79	2/5	-0.73	-0.44	0.85	17/4
295	Bangkok	28.13	-1.58	0.92	1.83	1/6	-1.08	-0.14	1.09	5/4
296	Medan	25.98	-0.60	0.34	0.69	2/6	-0.17	0.00	0.17	2/4
297	Fort Bayard	23.54	-6.13	-2.43	6.59	23/7	-0.56	-0.98	1.13	2/5
298	Aparri	26.11	-2.45	-0.46	2.49	12/7	-0.43	-0.46	0.63	25/4
299	Manila	26.59	-1.34	0.41	1.40	15/6	-0.61	-0.48	0.78	21/4
300	Iloilo	27.17	-0.92	0.22	0.95	18/6	-0.41	-0.45	0.61	26/4
301	Kolonie	27.23	-0.61	-0.20	0.64	20/7	0.17	0.09	0.20	15/1
302	Anna's Hope	26.06	-1.24	-1.00	1.59	10/8	0.04	-0.22	0.22	22/5
303	Fort de France	25.51	-0.94	-0.63	1.13	5/8	-0.24	-0.42	0.48	2/5
204	Richmond Hill, Grenada	26.35	-0.26	-0.19	0.32	7/8	-0.17	-0.09	0.19	16/4
305	Paramaribo	27.49	-0.10	-0.83	0.84	24/9	-0.66	-0.14	0.67	8/4

M.R.P. 917.

FIG 1. POSITION OF STATIONS. KEY NUMBERS.

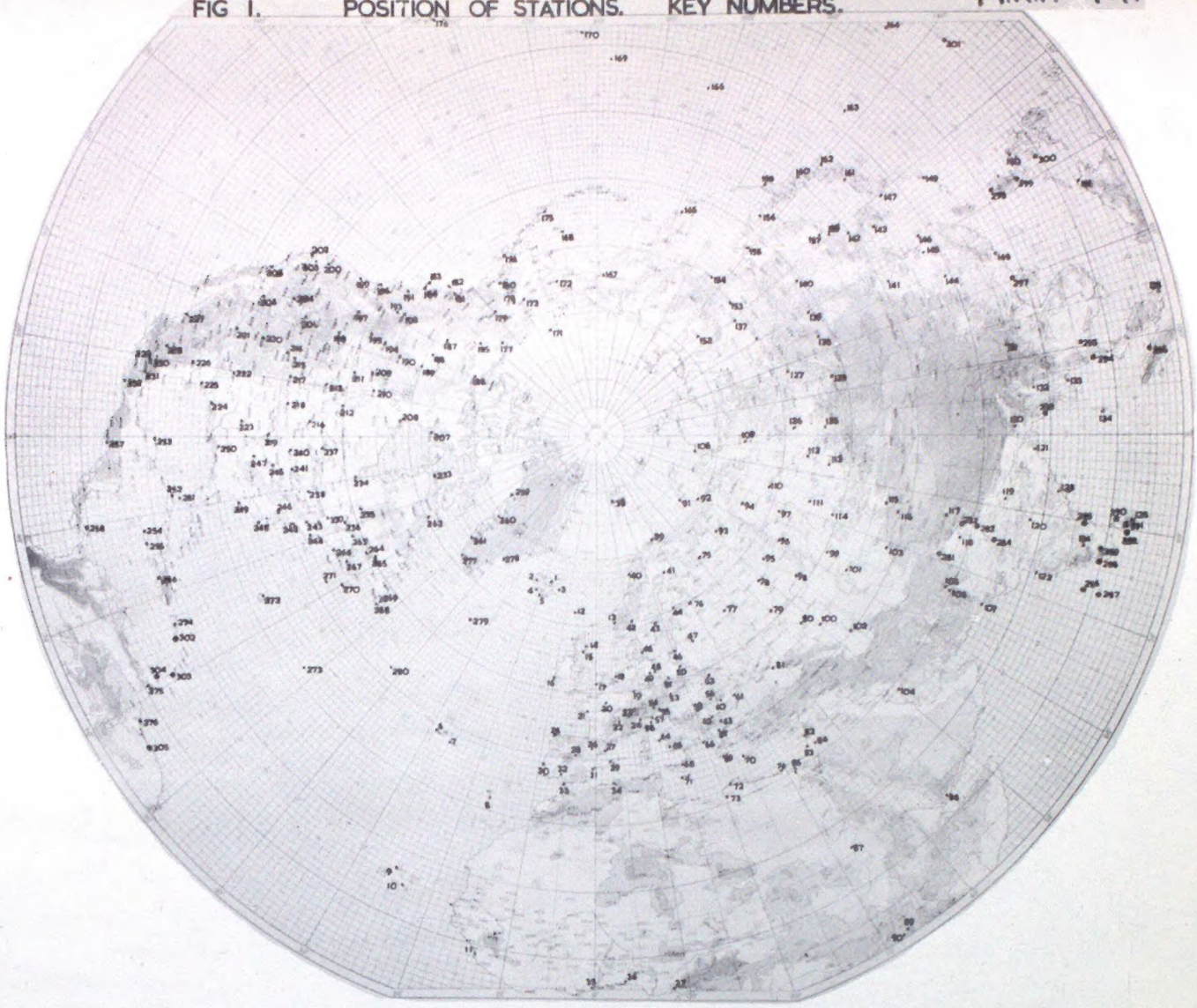
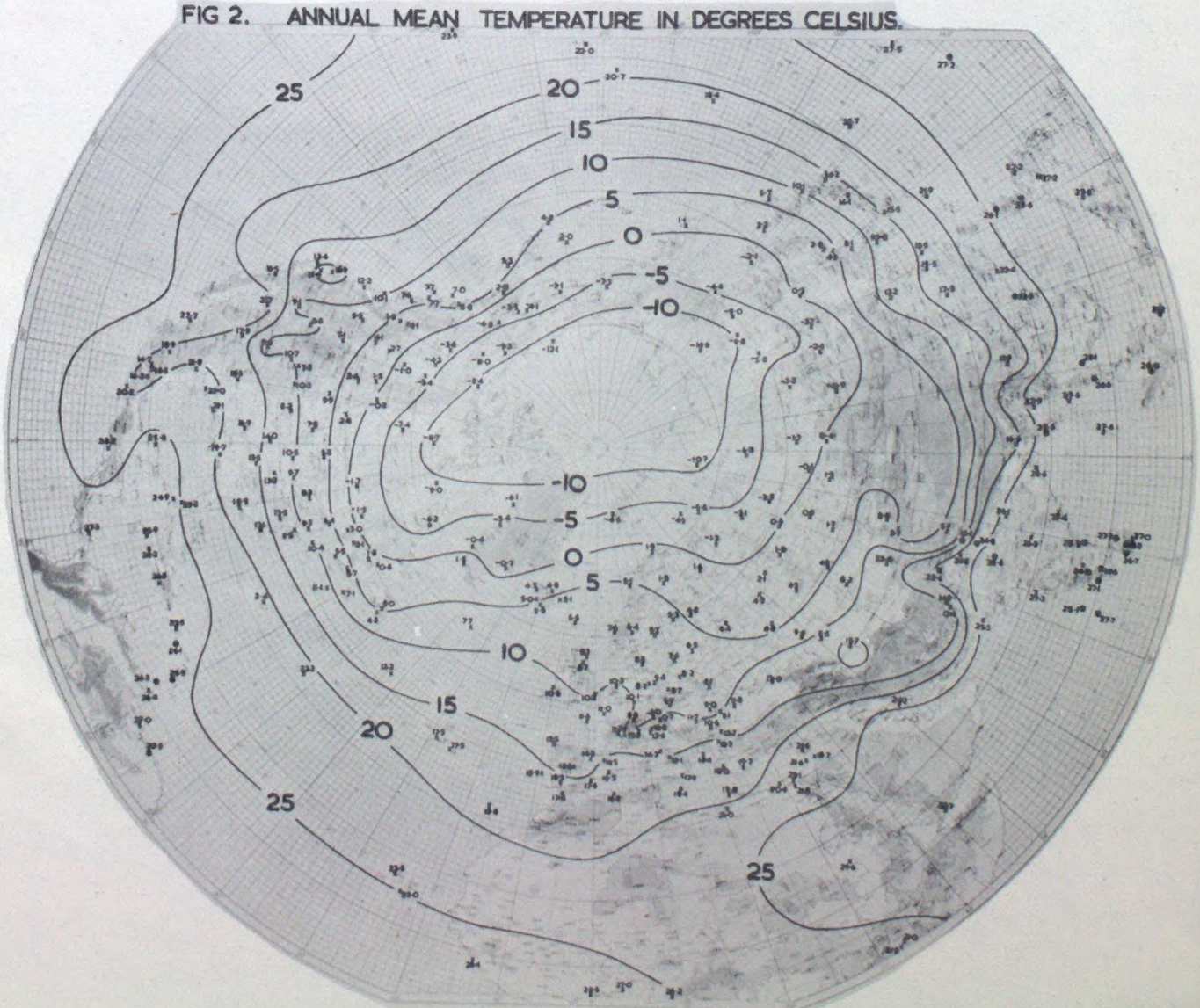


FIG 2. ANNUAL MEAN TEMPERATURE IN DEGREES CELSIUS.



M.R.P. 917.

FIG 3. SEMI-AMPLITUDE OF FIRST HARMONIC IN DEGREES CELSIUS.

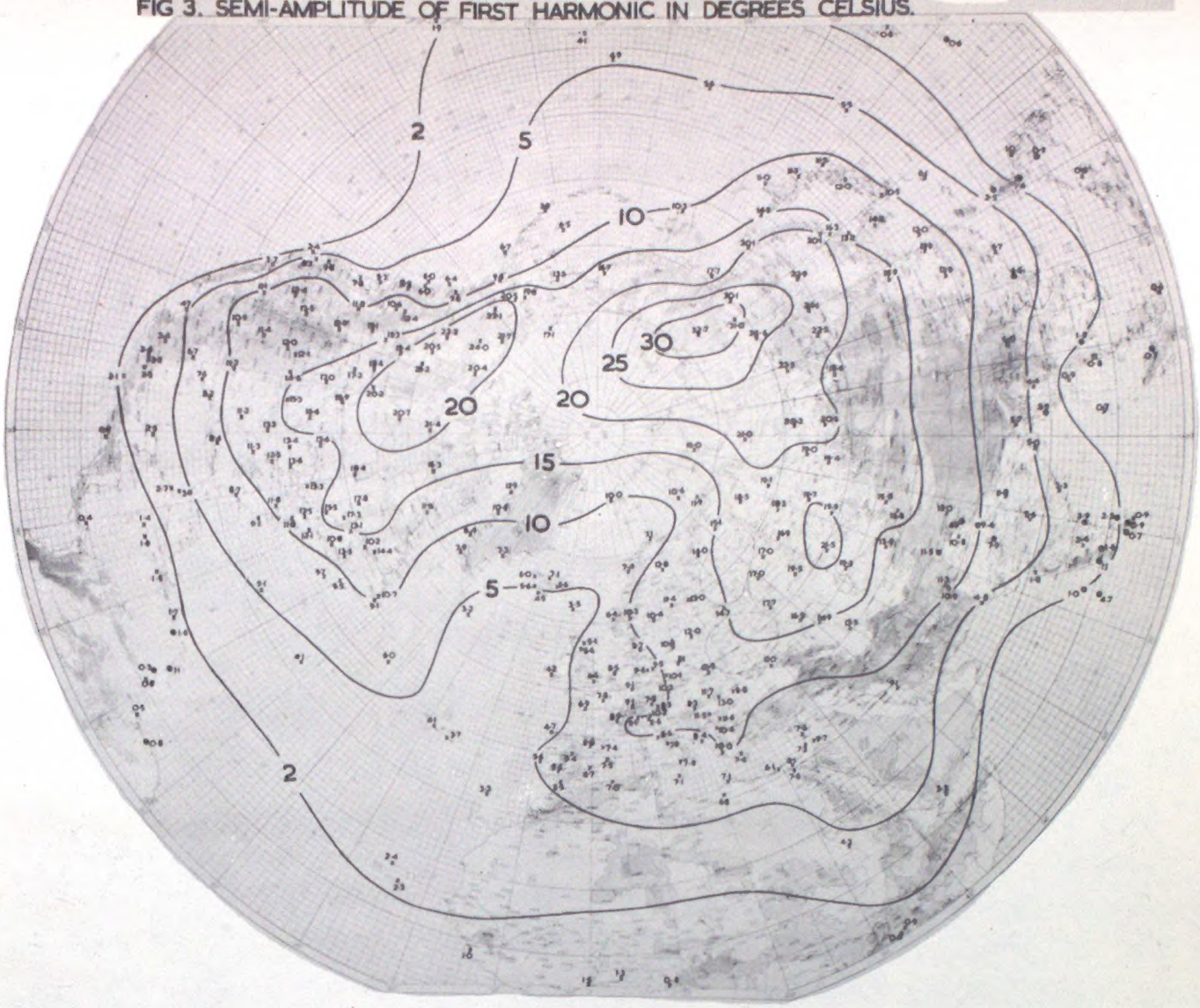
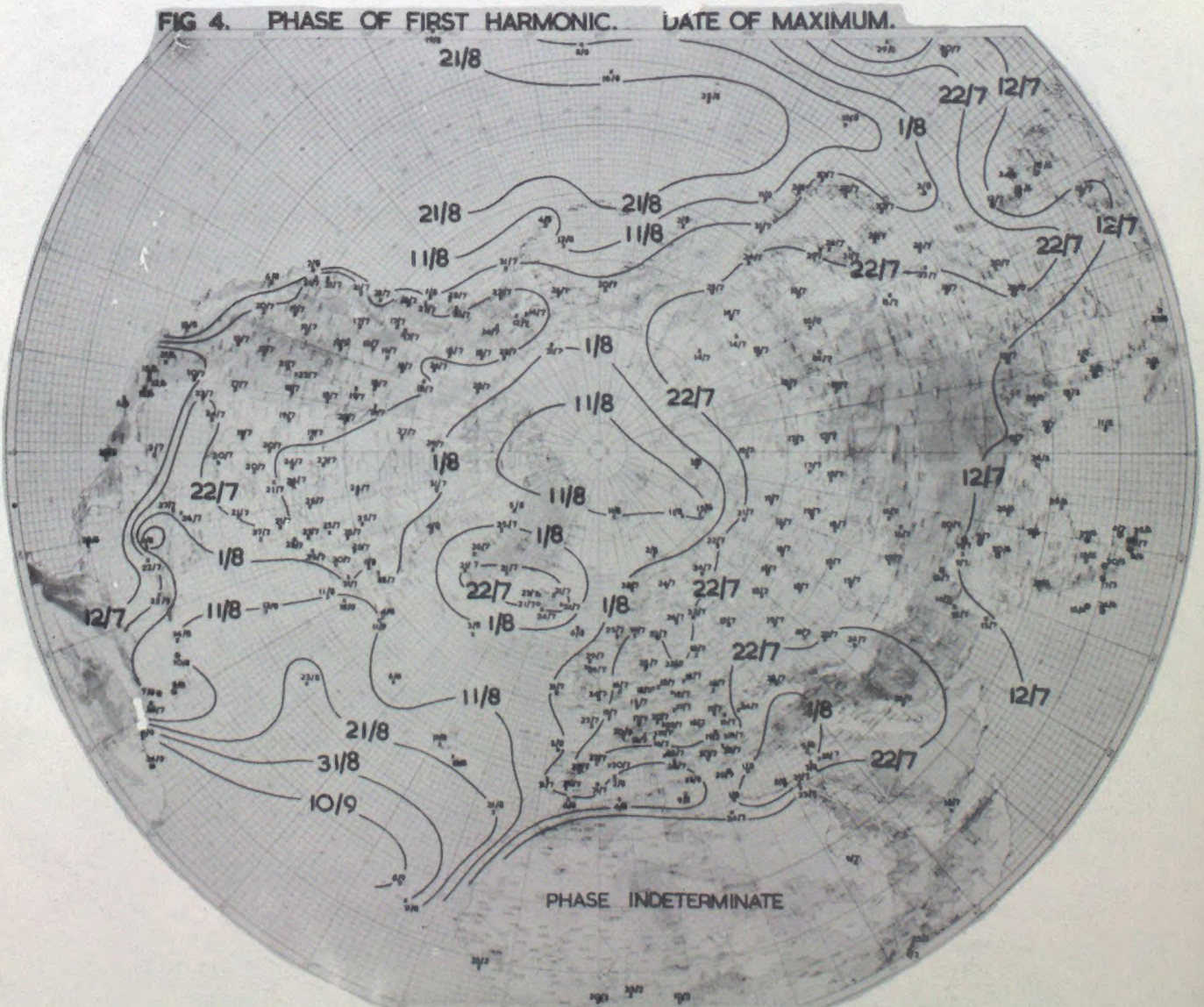


FIG 4. PHASE OF FIRST HARMONIC. DATE OF MAXIMUM.



M.R.P. 917.

FIG 5. SEMI-AMPLITUDE OF SECOND HARMONIC IN DEGREES CELSIUS.

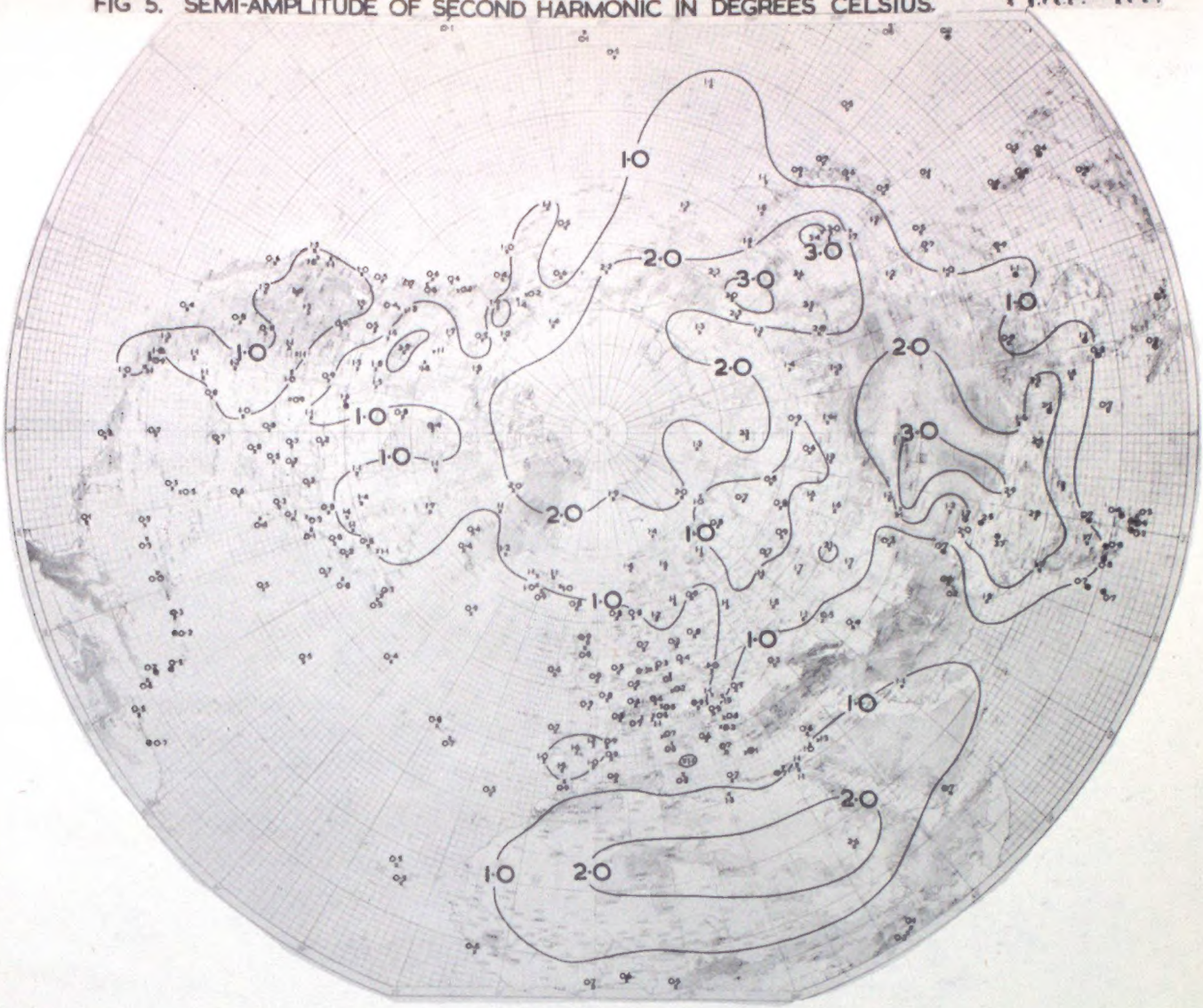


FIG 6. RATIO OF AMPLITUDES OF FIRST AND SECOND HARMONICS. ($A_2 / A_1 \times 100$)

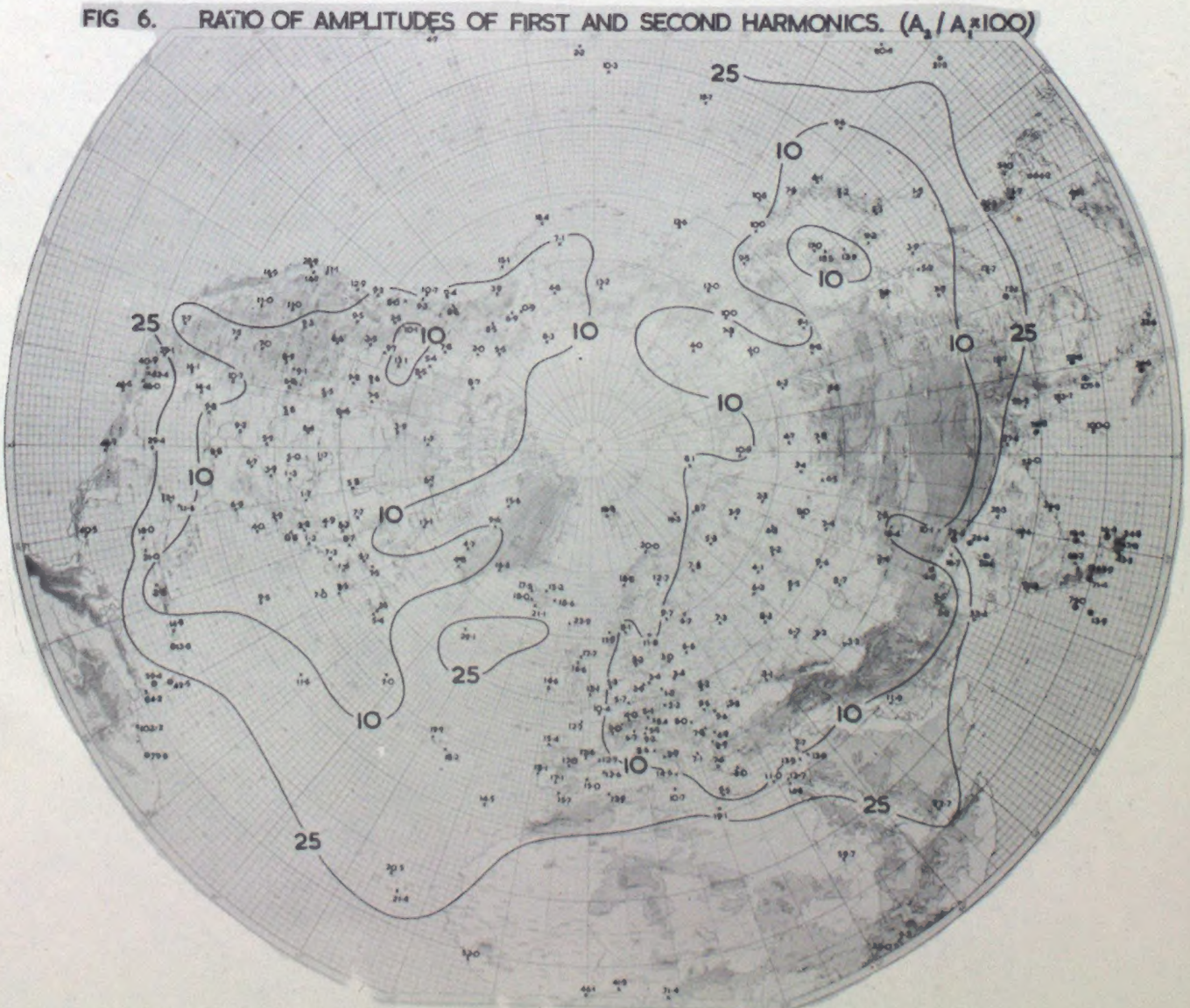


FIG 7. PHASE OF SECOND HARMONIC. DATE OF MAXIMUM.

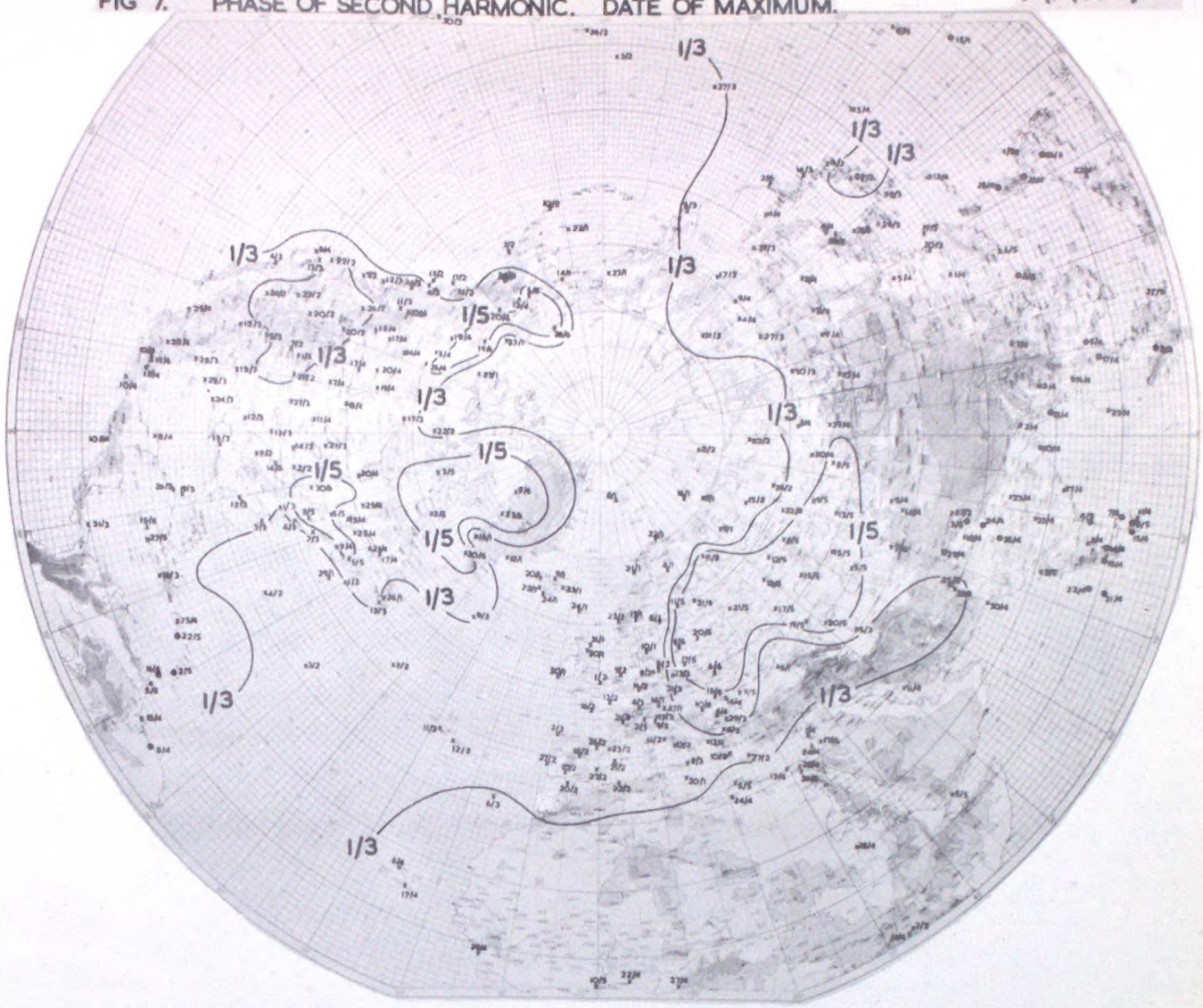
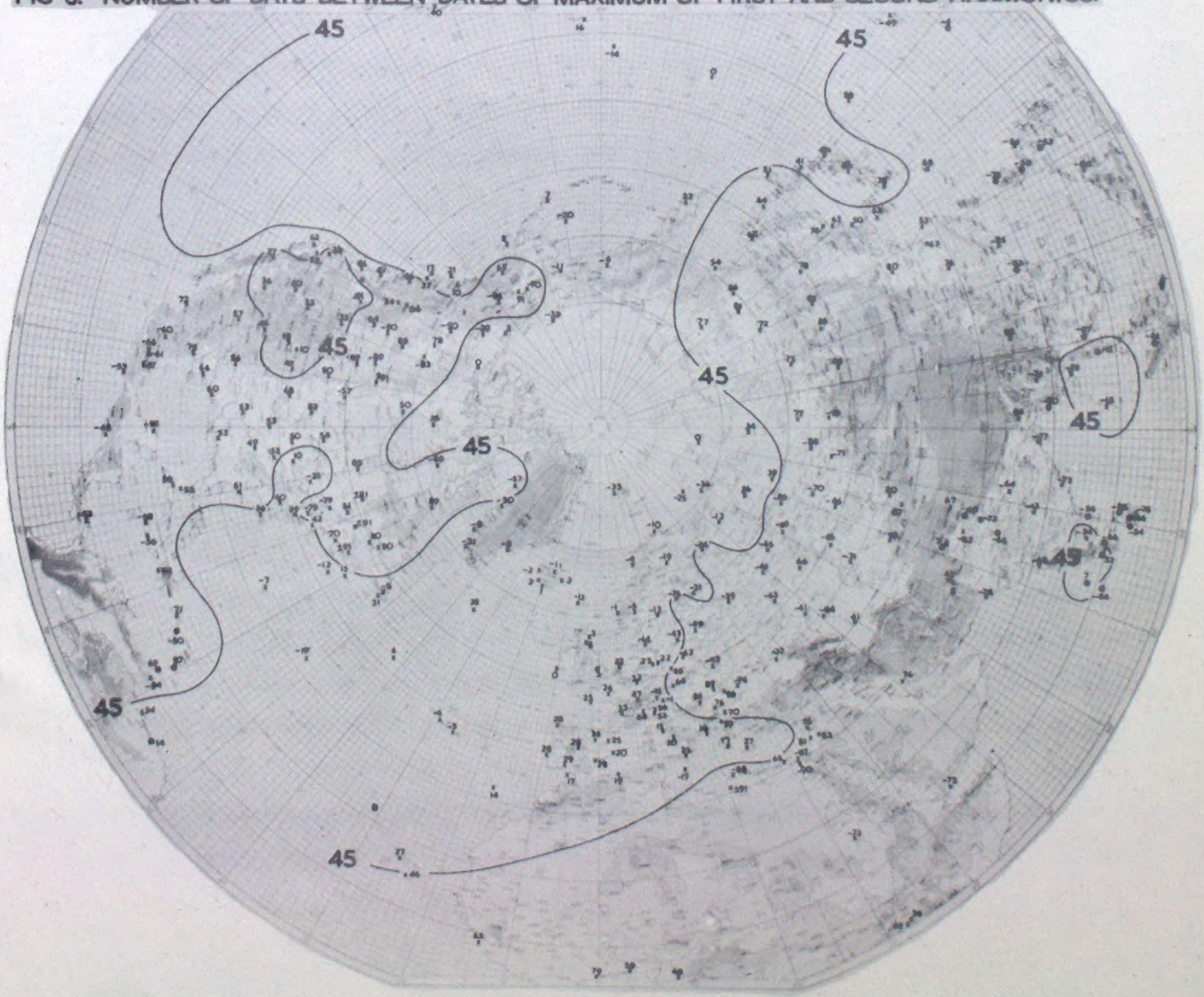



FIG 8. NUMBER OF DAYS BETWEEN DATES OF MAXIMUM OF FIRST AND SECOND HARMONICS.